NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

AIR LOGS FOR THE MEASUREMENT OF SUBSONIC

AND SUPERSONIC SPEEDS

By Rudolf Schmidt

Translation of "Luftlogs für die Messung von Unter-
and Überschallgeschwindigkeiten." Zeitschrift
für Flugwissenschaften, Heft 7, 1953.

LANGLEY RESEARCH CENTER

October 1958

AIR LOGS FOR THE MEASUREMENT OF SUBSONIC

AND SUPERSONIC SPEEDS

By Rudolf Schmidt

ABSTRACT

A discussion is given of the mechanical and aerodynamical require-
ments for air logs which must be set up if they are to give a satisfactory
accuracy over a wide range of speeds (up to the range of supersonic speeds)
and up to high flight altitudes. The theoretical considerations show that
these requirements can be met and that air logs are superior to all other
devices or methods for measuring speeds. A new type of air log which was
developed along these lines is briefly described.

INDEX HEADING

Instruments, Flight   8.1

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

AIR LOGS FOR THE MEASUREMENT OF SUBSONIC

AND SUPERSONIC SPEEDS[*]

By Rudolf Schmidt

SUMMARY

Air logs are used for measuring directly the flight speed of air-
craft. A discussion is given of the mechanical and aerodynamical require-
ments for air logs which must be set up if these instruments are to give
a satisfactory accuracy over a wide range of speeds (up to the range of
supersonic speeds) and up to high flight altitudes. The theoretical
considerations show that these requirements can be met and that air logs
are superior to all other devices or methods for measuring speeds. A
new type of air log is briefly described which was developed along these
lines at the Instituto Aerotécnico, Córdoba, Argentina.

1. INTRODUCTION

The speed of a body moving in an air space is determined usually by
measurement of the dynamic pressure of the flow, which is proportional
to the square of the velocity. Since all forces and stresses on a body
are directly dependent on the dynamic pressure, a special speed indicator
for their determination is not necessary. However, it is different when
flight path and flight performances are to be determined. If a pitot
tube is used, it is also necessary to determine the air density to make
the calculation of the speed from the dynamic pressure possible. This
presupposes knowledge of the static pressure and of the air temperature.
The measurement of these two quantities presents certain difficulties,
particularly when the process to be measured takes place at high alti-
tudes and at high speeds. Furthermore, a complication concerning measuring
technique is added when the flight speed approaches or even exceeds sonic
velocity because the compressibility of the air strongly affects the
aerodynamic properties of the pressure probes, particularly in the tran-
sonic region; as a result, the measuring accuracy decreases, of course.

A fundamentally different possibility of speed measurement is
offered by the air log. It consists of a small propeller which is
_____

freely rotatable in the flow and whose rotational speed is, or rather must be, proportional to the flight velocity. Actually, the air log is a device for measuring the distance travelled, and only by taking into consideration the time, is it transformed into a speedometer. The "ideal" air log operates completely independent of the air density and the Reynolds and Mach numbers; due to this property, it is superior to the pitot tube with respect to accuracy and simplicity, since measurment of the static pressure and of the air temperature is no longer necessary.

The mounting of the log-propeller shaft and the method for measuring its rotational speed at any time determine the extent to which the ideal condition may be approached. It seems that the difficulties which are involved have retarded the technical development of the air log on a large scale, so far. On the other hand, the reason may lie in the fact that the air log - because of its unfortunately unavoidable mechanical sensitivity - is not suitable for regular use aboard aircraft, and represents a device for flight testing only.

The external shape of the air log determines how far aerodynamic disturbance influences like the viscosity and compressibility of the air can be eliminated. This is undoubtedly possible if all present knowledge regarding flow phenomena in the subsonic and supersonic range is carefully taken into consideration; on this is based the second decisive advantage of the air log compared to the pitot tube since, as a result, all corrections, whose magnitude could be determined only by difficult calibrations can be omitted.

2. REVIEW OF THE HISTORICAL DEVELOPMENT

The main reason for the development of air logs was provided by the necessity for measuring small velocities where the pressure measure- ment is too inaccurate because of the quadratic relation between pres- sure and speed. However, the advantages of the direct speed-measuring instrument were soon recognized and attempts were made to develop air logs for regular use at normal flight speeds, also.

NACA Report No. 420 (ref. 1) contains a compilation of all con- struction types for air logs which had become known up to approximately the year 1932. One may distinguish two kinds: so-called "attached logs" and "towed logs." The first kind is fastened to a rigid supporting mast at a suitable point of the fuselage or wing. Since, however, in the neighborhood of the airplane the flow speeds deviate more or less markedly from the flight speeds, and since these differences depend, moreover, in every case on the flight attitude, towed logs were created that were trailed below the airplane by means of a long cable in practically

undisturbed flow. To the attached logs belong the American instruments of Pioneer, Stover-Lang, and a device of the Bureau of Standards, also the English RAE air log and the French instruments of Favre-Bull and Lavet-Berly. Towed logs were developed by Barr-Stroud and the Bureau of Standards in the U. S. A., by Dornier in Germany, and by the RAE in England. It is a remarkable fact that none of the older attached logs were provided with a movable support to make adjustment in the direction of flow possible in every individual case. For the first time, the air log developed in Germany later (1934) by Junkers was adjustable about the transverse axis for compensating changes in angle of attack, and the Dornier air log used since 1936 was the first to show a full universal-joint mounting.

The shafts of air logs were always supported in ball bearings. In the logs of Pioneer, Barr-Stroud, Lavet-Berly, Bureau of Standards, RAE, and Junkers, the rotational speed of the log propeller was reduced by a spur or worm gear, in order to facilitate the counting of the revolutions. This counting was always done with the aid of electrical methods, mostly with the aid of a collector which alternately opened and closed an electric circuit (Pioneer, Barr-Stroud, Lavet-Berly, Stover-Lang, RAE, Junkers) or else by indicating the rotational frequency with the aid of a frequency meter (Bureau of Standards). In all these air logs, the propeller had to furnish a torque so as to overcome the friction in the spur or worm gear and at the collector. The only air log where such a torque was completely lacking was the German instrument of the Dornier Company (refs. 2, 3, and 4). This device did not have reduction gears; the rpm measurement was performed by means of a photocell which was alternately illuminated and masked by a rotating shutter formed by the propeller hub. This instrument which, to the author's knowledge, doubtlessly represents the highest technical development in air logs was widely used in Germany during the Second World War. With the aid of it, measurements of speeds up to 800 km/h were performed. Further development and testing had to be discontinued at the end of the war. The instrument, developed for high subsonic speeds, is shown in figure 1.

3. VIEWPOINTS ON THE DESIGN OF AIR LOGS

The advantages in measuring technique for flight-speed measurements offered by the log can be fully utilized only when the log satisfies the condition that the ratio of rotational speed to flight speed, which we shall call "log constant," is a constant affected neither by air temperature and air density nor by Reynolds number and Mach number. In order to understand the properties of an air log and to be able to estimate the effect of the disturbing influences, we must first of all clarify the aerodynamic phenomena at the log propeller. For this purpose, we shall

start from the simple ideal case that the log propeller is completely
free to rotate and does not have to produce a torque from the aerodynamic
forces either for overcoming the bearing friction or for the measurement
of the rotational speed. We presuppose the blades of the log propeller
to be geometrically twisted so that the pitch is of the same magnitude
for any radius. Then one may visualize the profile as replaced by its
center line, and the total-force effect at the blade as concentrated on
the "effective" blade cross section lying on the radius r_{eff} (in analogy
to the procedure customary for propeller problems).

Figure 2 represents the velocity and force components for illustrating
the manner of operation. The resultant approach-flow velocity V_r is
vectorially composed of the flight speed V and the rotational speed U,
and forms with the axis of rotation the angle λ which is identical with
the "log constant." The aerodynamic forces acting on the blade are the
lift A and the air drag W; they must be so large that their resultant
X coincides with the direction of the axis of rotation, for only in this
case no torque originates. The force resultant X represents the axial
drag to be absorbed by the bearings of the propeller shaft.

From the triangles in figure 2, there results

$$\tan \lambda = \frac{U}{V} = \frac{A}{W} \tag{1}$$

Since U is always very small compared to V, one may put

$$\tan \lambda = \lambda$$

With the aerodynamic forces

$$W = \frac{1}{2} c_w F \rho V_r^2 \tag{2a}$$

$$A = \frac{1}{2} c_a F \rho V_r^2 \tag{2b}$$

one obtains

$$\lambda = \frac{c_a}{c_w} \tag{3a}$$

that is, the log constant is equal to the reciprocal profile lift-drag ratio. The angle of attack is

$$\alpha = \epsilon - \lambda \qquad (4)$$

and the lift coefficient in the required range

$$c_a = \alpha \, \frac{dc_a}{d\alpha} \qquad (5)$$

One obtains, therefore

$$\lambda = \frac{(\epsilon - \lambda) dc_a/d\alpha}{c_w} \qquad (6a)$$

We set $\dfrac{dc_a/d\alpha}{c_w} = K$ and, after a transformation, obtain finally

$$\lambda = \epsilon \, \frac{K}{K + 1} \qquad (7a)$$

The factor K is a purely aerodynamical quantity which depends only on the form of the log propeller and its profile. Since K increases when the lift gradient rises and the drag decreases, one may regard it as the "aerodynamic efficiency factor" for the blade and profile form. We shall call it below the "form factor." Its influence on the log constant may be recognized from figure 3. Here the ratio λ/ϵ is represented as a function of the aerodynamical form factor K. The curve with the parameter $N = 0$ refers to the log without torque. One sees that the log constant corresponds to the geometrical angle of pitch ϵ only for $K = \infty$. The smaller K, the larger becomes the difference between ϵ and λ, that is, the larger is the angle of attack α.

We now go a step further and investigate the conditions for a log whose propeller must produce a torque M, for instance, for overcoming the friction at a collector (fig. 4). In this case, an aerodynamic-force component T in the direction of the rotary motion must appear which corresponds to the torque M acting at the shaft. The resultant aerodynamic force now no longer coincides with the direction of the axis of rotation but forms with it an angle φ which we shall call "angle of friction." Thereby, the following relationships result. One has

$$\lambda + \varphi = \frac{c_a}{c_w} \tag{3b}$$

and with equations (4) and (5)

$$\lambda = \frac{\epsilon K - \varphi}{K + 1} \tag{7b}$$

The friction angle φ is proportional to the torque to be braked. If one calls the ratio $\varphi/\epsilon = N$ the "friction coefficient" and introduces it into equation (6b), one obtains the formula

$$\frac{\lambda}{\epsilon} = \frac{K - N}{K + 1} \tag{7c}$$

which is likewise represented in figure 3 with N as parameter. For such a log the difference between the log constant λ and the geometrical angle ϵ is still larger than for the log without torque. At the same time, one can recognize from the representation that λ changes when the factor N, that is, the friction angle φ for the log in question changes. Hence, one may derive the following fundamental condition which must be satisfied for an ideal air log: The friction angle must be constant and independent of external influences (changes in pressure, temperature, viscosity, friction, humidity, etc.).

We shall now investigate the relationship between the friction angle and the torque at the shaft and the required character of the torque so that the above condition can be satisfied.

The torque is

$$M = Tr_{eff} \tag{8}$$

with the tangential aerodynamic-force component

$$T = \frac{1}{2} c_t F \rho V_r^2 \tag{9a}$$

If one puts

$$V_r^2 = V^2 + U^2 = V^2\left(1 + \lambda^2\right)$$

one obtains

$$T = \frac{1}{2}\, c_t F \rho V^2 \left(1 + \lambda^2\right) \tag{9b}$$

Since the friction angle is, according to figure 4

$$q = \frac{c_t}{c_x}$$

c_t must be constant too, if q is to be constant, that is, one must have

$$\frac{M}{\frac{1}{2}\rho V^2} = \text{Constant} \tag{10}$$

The torque to be braked M must therefore be proportional to the dynamic pressure $\frac{1}{2}\rho V^2$, and the quantity $\dfrac{M}{\frac{1}{2}\rho V^2}$ must be independent of external disturbing influences. There now arises the question as to whether and how it is practically possible to satisfy this condition, or as to what properties an air log possesses for which this condition is not rigorously satisfied.

3.1. The Torque of the Log-Propeller Support

The support of the shaft must carry the weight of the movable parts and absorb the axial thrust. The frictional torque produced by the weight loading of the bearings is proportional to the weight and therefore a constant, whereas the moment produced by the axial thrust is proportional to the latter. Since the axial thrust is proportional to the dynamic pressure, one can see that the contribution of the weight to the torque does not satisfy the condition set up above, but that the contribution of the axial force does satisfy it. The friction coefficients which affect the magnitude of the friction moments may be

generally regarded as constant in shaft supports if one succeeds in avoiding the influence of temperature changes on the lubricant friction. Nowadays, there exist minute ball bearings and special lubricants which make this possible without any difficulty.

3.2. The Torque of the Device for Transmission

If the transmission of the revolutions of the log's propeller takes place with the aid of a collector or commutator, there originates at the latter, from the friction of the brushes, a torque which has the same properties as that of the dead weight loading, that is, practically constant. If, on the other hand, the rpm of the log's propeller is measured by means of a generator driven by the propeller, the torque is approximately proportional to the rotational speed.

One has therefore to distinguish four cases:

(a) $M = 0$ (ideal case)

(b) $M = $ const.   (bearing friction due to dead weight, collector friction)

(c) $M = f\left(\frac{1}{2}\rho v^2\right)$ (bearing friction due to axial resistance)

(d) $M = f(v)$ (torque of a generator)

The ideal case (a) cannot be realized technically, since the bearing friction cannot be eliminated; thus, the two moments (b) and (c) always appear jointly. The moment in case (d), in contrast, can be completely avoided if a method is chosen for the rpm measurement which does not require a generator.

In the previous section, it was shown that a torque which is proportional to the dynamic pressure is perfectly admissible and does not interfere with the desired behavior of an ideal air log. The result found is, therefore, that only cases (b) and (d) are undesirable and thus must be suppressed as far as possible if the deviations from the ideal behavior are to be kept negligibly small.

Most important is the investigation of the question as to how a log behaves under the effect of the unavoidable friction moment of the bearings due to the dead weight. With the aid of equations (8) and (9b), one may derive that for $M = $ constant the relationship

$$N = \frac{\text{Constant}}{\frac{1}{2}\rho v^2} \tag{11}$$

is valid. Since in a modern aircraft the dynamic pressures between landing and maximum speeds are in the ratio of 1:25 and more, one can see that, within the range of application of the log, the friction coefficient N likewise may change in this ratio. In order to be able to determine the influence of this change on the log-constant λ, we define the concept of "relative sensitivity" ∂λ/λ ∂N which indicates, in percent, that change of λ which occurs in the case of a change ∂N = 1 or ∂φ = ε. Its value is obtained from equation (7c) by differentiation. One has

$$S_N = \frac{\partial \lambda}{\lambda\, \partial N} = -\frac{1}{K-N} \tag{12}$$

This function is represented in figure 5. It shows that an aerodynamically satisfactory log (with high form factor K) is considerably less sensitive to a change in the friction coefficient N than a log with low aerodynamic efficiency. In order to obtain an idea of the order of magnitude of the relationships, the behavior of a modern air log (Dornier) was numerically investigated. The following values resulted:

(a) For maximum speed with $\frac{1}{2}\rho V^2$ = 5000 kg/m² there is

$$N = 6.25 \times 10^{-3}$$

(b) For landing speed with $\frac{1}{2}\rho V^2$ = 200 kg/m², N becomes

$$N = 40.8 \times 10^{-3}$$

Thus

$$\partial N = 34.55 \times 10^{-3}$$

and for

$$K = 100$$

there results

$$\frac{\partial \lambda}{\lambda} = 0.035 \text{ percent}$$

This variation of λ is much smaller than the practically admissible margin of error, even with the highest requirements regarding measuring accuracy.

In a log with M = constant, there appears also an undesirable dependence of the log constant on the air density ρ and thus on the flight altitude. Let us assume that for the air log on which the investigation is based in one case of speed $V = 100$ m/s is to be measured near the ground, in the other case at 15-km altitude. Near the ground, the dynamic pressure is $\frac{1}{2}\rho V^2 = 625$ kg/m^2 and thus $N = 16.3 \times 10^{-3}$; at 15 km altitude, $\frac{1}{2}\rho V^2 = 98$ kg/m^2 and $N = 78.5 \times 10^{-3}$. Thus one obtains $\partial N = 62 \times 10^{-3}$, and for $K = 100$, the change of the log constant would be $\partial\lambda/\lambda = 0.062$ percent. This dependence on altitude of the log is so slight that it may always be neglected for practical purposes.

We conclude from the preceding calculation that it is possible to construct air logs for which the detrimental influence of the unavoidable bearing friction is so slight that corrections for dynamic pressure and altitude are unnecessary in practical applications. However, this is guaranteed only when solely the bearing friction is present and the rpm measurement does not require a torque. One may keep the influence of the detrimental bearing friction sufficiently small by making the weight of the rotating parts as small as possible and using specially selected ball bearings with good operating characteristics. In section 4, we shall come back to the methods of an rpm measurement which is "free from reaction."

We now turn to the consideration of the aerodynamic influences. As has already been derived, the aerodynamic form factor $K = \dfrac{dc_a/d\alpha}{c_w}$ is here decisive. For a good air log, it should be as large as possible, with consideration of the injurious effect of the bearing friction; on the other hand, it should vary as little as possible in the entire range of application of the device. For characterization of its influence, one can define a "relative sensitivity" of the device to variations of K; we obtain it from equation (7c) by differentiation:

$$S_K = \frac{\partial\lambda}{\lambda\,\partial K} = \frac{N+1}{(K+1)(K-N)}$$

It is represented in figure 6. Thus, the sensitivity S_K is the greater, the smaller the form factor K and the larger the friction coefficient N. If one takes as the admissible upper limit of error, due to changes in the aerodynamic phenomena at the log's propeller, the value 0.1 percent,

the form factor may vary by an amount of, at most, ±10 for a log free
from torque and with a mean form factor K = 100. For a log with N = 1,
this amount is reduced to one half.

3.3. Influence of the Profile Form, of the Reynolds

and Mach Numbers on the Form Factor K

In order to determine whether this condition can be satisfied in
practice, we must investigate how the form factor K changes as a
function of the profile form as well as of the Reynolds and Mach numbers.
We base this investigation on the following profile forms:

(a) Wedge profiles with the wedge angles $2\beta = 3^{\circ}$, 6°, and 9°

(b) Trapezoidal profiles with the wedge angles $2\beta = 6^{\circ}$ and 12°

Profiles with cambered surfaces are unsuitable because they are difficult
to manufacture and also because they have a critical Reynolds number at
which the boundary-layer condition abruptly changes, which causes
undesirable aerodynamic effects. The favorable effect of a sweepback
of the airfoil on the critical Mach number may be utilized also for the
air log; therefore, we shall also investigate this effect for the two
sweepback angles $\psi = 0^{\circ}$ and $\psi = 50^{\circ}$.

The lift gradient $dc_a/d\alpha$ is for a sweptback wing with aspect
ratio Λ

$$\frac{dc_a}{d\alpha} = \frac{2\pi\eta}{\sqrt{1 - \cos^2\psi Ma^2} + 2\eta/\Lambda}$$

This law is valid until sonic velocity is attained locally on the pro-
file when, as a result of the compression shocks which then occur, the
flow pattern is changed fundamentally. Since, in a log, the profile
angles of attack and also the c_a values are extremely small, it is
advantageous to use symmetrical and relatively thin profiles for which
the local excess velocities are very small. Therefore, one succeeds
easily in postponing the occurrence of compression shock until close
to the effective Mach number 1. Thus, the above law is valid almost up
to $Ma_{eff} = 1$. η is the profile coefficient.

In passing through the velocity of sound, the aerodynamic processes
change fundamentally; so far, however, we are not yet in a position to
express them by a law. This is again possible only when starting with

12

that Mach number at which the bow wave adheres to the profile nose. The slenderer the profile nose, the earlier this phenomenon occurs. For the wedge profiles that were chosen, this is the case at the following Mach numbers:

$$\text{For wedge angle } 2\beta = 3^{\circ} : Ma = 1.09$$

$$\text{For wedge angle } 2\beta = 6^{\circ} : Ma = 1.16$$

$$\text{For wedge angle } 2\beta = 9^{\circ} : Ma = 1.24$$

$$\text{For wedge angle } 2\beta = 12^{\circ} : Ma = 1.29$$

Above this Mach number, the lift gradient obeys, according to the so-called theory of the second approximation (ref. 5), the following laws:

(a) For the trapezoidal profile one has

$$\frac{dc_a}{d\alpha} = 2 \cos \psi C_1 \left[1 - \frac{1 - 2\beta C_2/C_1}{2\Lambda\sqrt{\cos^2\psi Ma^2 - 1}} \right]$$

where

$$C_1 = \frac{2}{\sqrt{\cos^2\psi Ma^2 - 1}}$$

and

$$C_2 = \frac{\kappa \cos^4\psi Ma^4 + (\cos^2\psi Ma^2 - 2)^2}{2(\cos^2\psi Ma^2 - 1)^2}$$

and κ signifies the adiabatic exponent.

(b) For the wedge profile:

$$\frac{dc_a}{d\alpha} = 2 \cos \psi \left(C_1 + 2\beta C_2 \right) \left(1 - \frac{1 - \beta C_2/C_1}{2\Lambda\sqrt{\cos^2\psi Ma^2 - 1}} \right)$$

The drag consists of the components friction drag, form drag, induced drag, and wave drag. The drag originating from the tangential forces at the surface depends on the roughness of the latter and on the Reynolds number. The Reynolds number may vary to a rather high degree, according to the flight speed and flight altitude. Assuming a mean profile chord of the log propeller blade of 2.5 cm, one obtains approximately the following limiting values: For an aircraft flying near the ground, at sonic velocity, the Reynolds number is $Re = 6 \times 10^5$; at landing speed, $Re = 10^5$. In the case of aerodynamically smooth surface, laminar boundary flow prevails in the entire range of these Reynolds numbers, and the well-known law

$$c_f = \frac{1.327}{\sqrt{Re}}$$

applies for the friction drag.

The c_f values may therefore fluctuate within the range

$$0.002 < c_f < 0.0042$$

We shall at first calculate with a mean value $c_f = 0.003$ and shall discuss the influence of variations in the Reynolds number once more, later on, in more detail. The mean friction-drag coefficient for a slender profile thus becomes $c_{WF} = 2c_f = 0.006$.

The form drag of the plane, infinitely thin plate, is zero. In the case of a wedge profile with a blunt rear edge, the form drag originates almost solely from the negative pressure of the rear side. Its magnitude depends on the friction drag and is according to an empirically found function (ref. 6) in the subsonic range

$$c_{wB} = \frac{0.135}{\sqrt[3]{c_{wF}/2\beta}} \, 2\beta$$

Since according to Prandtl's rule the pressures in compressible flow vary in the neighborhood of the profile in the ratio $\dfrac{1}{\sqrt{1 - Ma^2}}$, one may assume that the pressure in the dead water also undergoes this variation; thus

14

$$c_{wB} = \frac{0.27\beta}{\sqrt{1 - Ma^2} \sqrt[3]{c_{wF}/2\beta}}$$

In the supersonic range, the rear-side pressure p is, compared to the dynamic pressure q, theoretically

$$\left(\frac{p}{q}\right)_{theor} = \frac{2}{\kappa Ma^2}$$

According to measurements, however, this theoretical value is never reached. In accordance with experience, one may except, for profiles with a blunt rear edge, an efficiency factor 0.7 so that one obtains with $\kappa = 1.4$

$$c_{wB} = \frac{2\beta}{Ma^2}$$

A measurement (fig. 7) performed in the wind tunnel with wedge and trapezoidal profiles shows that with the latter the drag may be considerably reduced. It amounts only to about one-fourth of the drag of a wedge profile of the same relative thickness.

In the supersonic range, the form drag of the trapezoidal profile may be calculated theoretically; it is then identical with the wave drag. The contribution of the induced drag is completely negligible; the angle of attack α and the lift coefficient c_a are always extremely small for a log satisfying the requirements which are necessary for practical purposes, with respect to bearing friction and to the sensitivity regarding mechanical and aerodynamic influences caused by it.

For the wave drag, one obtains according to the so-called theory of the second approximation in the case of a wedge profile and an angle of attack $\alpha = 0^o$

$$c_{wc} = 2 \cos^3\psi \left(C_1\beta^2 + C_2\beta^3\right)$$

in that of a trapezoidal profile

$$c_{wc} = 2 \cos^3\psi C_1\beta_2$$

where C_1 and C_2 are the coefficients already mentioned. These formulas for the wave drag also apply only when the bow wave adheres to the

profile nose, that is, when supersonic flow prevails everywhere. The transonic region where the bow wave is detached from the profile is the smaller, the sharper the profile. Since experimental data are lacking, we cannot make any certain statements regarding the aerodynamic forces in this region.

According to the formulas mentioned above, the aerodynamic-force coefficients of the chosen profiles were calculated and the K values determined from them. In figures 8 and 9, the K values are represented as a function of the Mach number. A certain unreliability in the variation exists, for the reasons mentioned above, only in a narrow range at $Ma_{eff} = 1$ which is the wider, the larger the wedge angle of the profile. In this range, a pronounced increase of K takes place. A comparison of the profiles shows clearly that the slender profiles with small wedge angle are superior. For equal wedge angles, the trapezoidal profiles are considerably superior to the wedge profiles with blunt rear edge. They are still more favorable than those even when their wedge angle is twice as large, that is, when their thickness ratio d/c is equal. With a trapezoidal profile with $2\beta = 12^o$ and a sweepback $\psi = 50^o$, one attains K values of the order of magnitude of approximately 120. The sensitivity to aerodynamic influences for such a log is extraordinarily small. With the aid of figure 6, one obtains for instance, for a friction coefficient $N = 1$, a sensitivity $S_K = 0.00014$. Variations of K of the order of magnitude of $dK = \pm 30$ compared to the mean value, as occur for the trapezoidal profile with 12° wedge angle, have therefore an effort of approximately 0.4-percent variation of the log constant λ. Such a log may therefore be applied at an arbitrary Mach number without compressibility effects at the log's propeller having a practically significant effect on the measured result.

The same is true regarding the influence of the Reynolds number. We found in calculating the friction drag that its amount may fluctuate by 30 to 40 percent, according to the Reynolds number. However, since the friction drag amounts in the most unfavorable case to only one-half to one-third of the total drag, even for a very slender profile, the K value can fluctuate at most by 15 to 20 percent, that is, the fluctuations produced by viscosity effects are certainly smaller than those produced by compressibility and, therefore, likewise without detrimental influence on the measured result. Solely at extreme flight altitudes that were attained only by unmanned rockets so far, the influence of the viscosity becomes so large that it must be taken into consideration in the evaluation of the measured values.

The influence of the sweepback on the form factor K is expressed by the fact that the uncertain part of the transonic region is shifted to a higher Mach number. By means of the sweepback, one can therefore adjust the log better to its purpose in every case. Regarding the form

factor K, the sweepback has no particular significance; however, we shall see in the following section that it is of advantage in other respects.

3.4. Influence of the Log Body and Its Support

A log body for housing the support for the log propeller and the transmission elements for the rpm measurements is unavoidable, likewise a supporting mast or post on which the device is fastened, as far outside as possible from the object to be measured. To this body, too, applies the requirement to make it as slender as possible in order to reduce the flow disturbance produced by it at the location of the log's propeller as well as the total drag of the device. An acute cone of revolution with an opening angle of 8° to 10° appears to be the best form, particularly with regard to application in supersonics. The velocities induced by the cone are very small; the result of a measurement on a 10° cone is shown in figure 10. Hence, there results a disturbance velocity of about -0.7 percent at the location of the "effective radius" if the log propeller is arranged at the cone vertex. In approaching sonic velocity, this disturbance velocity increases according to Prandtl's rule and attains, for instance, for Ma = 0.9 the magnitude of -1.6 percent. One could avoid this influence by arranging the log's propeller not at the cone vertex, but at that location of the cone where the static pressure is equal to the static pressure of the undisturbed flow. However, this would be favorable only for a log to be applied only in the subsonic range. For the supersonic state, it is better to arrange the log's propeller at the vertex of the cone in order to avoid the disturbance zone situated behind the Mach cone. Also, for this reason a forward sweep of the log's propeller is more favorable than a sweepback.

In order to avoid flow disturbances due to the supporting mast, it is useful to attach it to the airplane in the direction of the approach flow and to fasten the log to its tip. In this manner, one also obtains the least air drag and one may be certain that at supersonic velocity the device is in front of the Mach cone of the airplane.

It is absolutely necessary to fasten the log to the supporting mast by means of a universal joint since the log constant is very sensitive to variations of the direction of the approach flow. For the same reason one must make sure, by mass balance, that the center of gravity of the log is located exactly at the center of rotation of the suspension. The aerodynamic stabilization must be performed by guide vanes which lie behind the center of rotation. These latter also have the purpose of achieving as high a damping of disturbance motions as possible. It is of no importance what shape the tail assembly is given. One may form it, similarly as for an airplane, of crossed surfaces which are attached

to the rear end of the cone body, or of a cylindrical ring connected with the cone body by supports.

4. THE METHODS FOR RPM MEASUREMENT "FREE FROM REACTION"

Transmission and measurement of the rpm "free from reaction" signify that no work output is required which has to be produced by the log's propeller. However, since every device which serves either for indication or for recording of the log revolutions consumes a certain output, this latter must be taken from a special energy source separated from the log's propeller, while the log's propeller appears only as a controlling organ. For this objective, only electrical methods may be considered in practice because they have the advantage - compared to mechanical methods - of having no friction and practically no inertia. Following, some possibilities for this are discussed.

4.1. The Photoelectrical Method

This method applied in the Dornier log consists of a light shutter being connected with the log-propeller shaft which, in phase with the revolutions, lets the light of a small electric bulb L or direct daylight fall on a photocell C located inside the log's body and thus periodically varies the electrical resistance of the photocell (fig. 11). There originates, therefore, in the circuit of the photocell, fluctuations in voltage whose frequency is equal to the rpm of the log. They may serve for controlling a magnetic or electrical relay which after sufficient amplification yields electrical current impulses which drive an electromagnetic counting or recording device. In figure 11, the photocell C is connected to the input tube by potentiometer connection; as a result of its periodical exposure and blackout by the revolving log, fluctuations in voltage originate at the control grid. This latter has an initial bias voltage which prevents the use of grid current. The anode-current fluctuations originating in the input tube are amplified in two further stages and actuate finally a small electromagnet M in the recording device. For the indicated connection, the amplifier tubes are operated with an anode voltage of only 24 to 27 volts which are available from the aircraft electrical system; thereby, a special current source for the supplying of the amplifier is unnecessary and the cost thus reduced. Since only impulse frequencies are transferred by the device, fluctuations in voltage or other external disturbances do not have any influence on the measuring accuracy.

4.2. Inductive Methods

In figure 12, a method is represented in which the electromotive force induced in an air-cored coil B by a permanent magnet J which rotates with the log's propeller is used to control an electron relay. By changes in potential at the control grid of the input tube caused by the rotation of the magnet, the input tube is periodically opened and closed so that in the plate circuit current fluctuations originate which are amplified in two further stages. The initial grid voltage at the input tube is chosen so that no grid current flows even at the largest occurring changes in potential. This prevents any reaction on the log's propeller. The anode-current fluctuations at the amplifier exit operate the electromagnet M of the counting or recording device.

Whereas, according to the methods described above, one measures the frequency of the rpm impulses, one may also directly measure the electromotive force induced in the coil of the log, using a so-called "vacuum-tube voltmeter." Thus, one obtains the possibility of direct indication of the rotational velocity since the induced electromotive force is directly proportional to the rotational velocity. The accuracy of the indication depends on the supply voltages being kept constant and is, therefore, mostly lower in flight operation than the accuracy in frequency measurements.

5. CONCLUDING REMARKS

From the investigations that were carried out, one can see that it is possible, with the means available at present, to build air logs which operate independently of the flight attitude, the altitude, and the Mach number. Based on the results of these investigations, a new air log was developed at the Instituto Aerotécnico Córdoba (Argentina) which is represented in figure 13. It has a propeller of 40° forward sweep with two blades which have a rhombic profile with 6° nose angle. The geometrical pitch is about 5.5 m so that, at sonic velocity, approximately a rotational speed of 50 revolutions per second is attained. The log-propeller shaft is supported in special miniature ball bearings. For the transmission of the revolutions, an inductive method according to the principle of figure 12 is used. The tail consists of a ring held by three supports which have trapezoidal profiles. The log is mounted by means of a universal joint. A cone with 8.5° vertex angle forms the log's body. The log proper weighs only 0.260 kg. The measuring errors which are due to viscosity and compressibility effects, determined by calculation, do not exceed the order of magnitude of ±0.5 percent for any flight attitude below 30 km altitude. A checking of the magnitude

of this error by calibration and test is hardly possible in practice since all measuring methods available for this purpose have greater inaccuracy.

Translated by Mary L. Mahler
National Aeronautics and Space Administration

REFERENCES

1. Beij, K. Hilding: Aircraft Speed Instruments. NACA Rep. 420, 1932.

2. Schmidt, R.: Das Dornier-Luftlog, ein neues Meßgerät für Flugversuche.
   Jahrb. 1938 der deutschen Luftfahrtforschung, R. Oldenbourg (Munich),
   p. I 583.

3. Schmidt, R.: Dornier-Luftlog. Bericht Vers. 101 d. Dornier-Werke
   Friedrichshafen, 1943.

4. Schmidt, R.: Das Dornier-Luftlog. Ber. Nr. 181 der Lilienthal-Ges.
   f. Luftfahrtforschung, 1944.

5. Bonney: Engineering Supersonic Aerodynamics. McGraw-Hill Book Co.,
   Inc., 1950.

6. Horner: Base Drag and Thick Trailing Edges. Jour. Aero. Sci.,
   vol. 17, 1950, p. 622.

7. Blumenstock: The Upper Atmosphere. Sci. American, Jan. 1949.
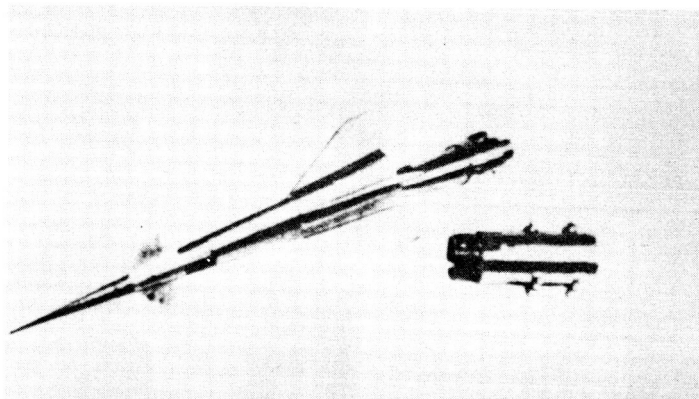
Figure 1.- The Dornier air log for high subsonic velocities.
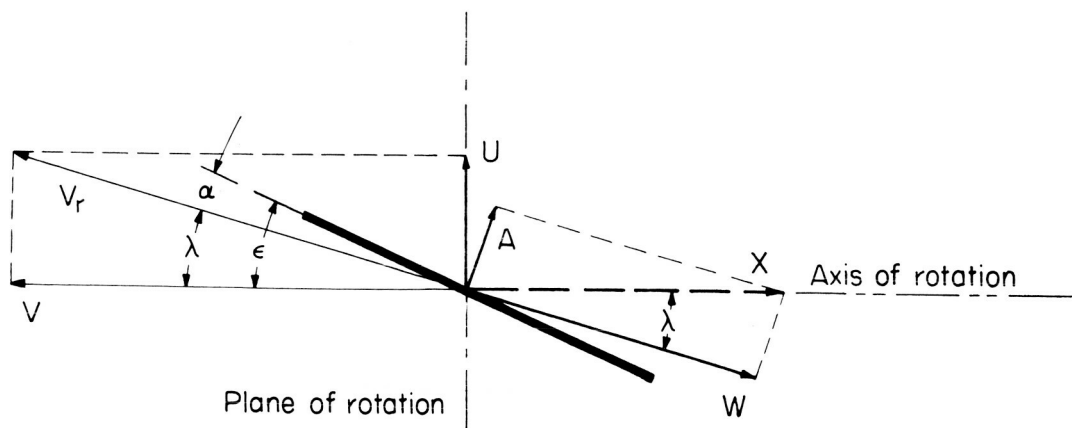
Figure 2.- Velocity and aerodynamic force components on the
"effective" blade section for torque = 0.
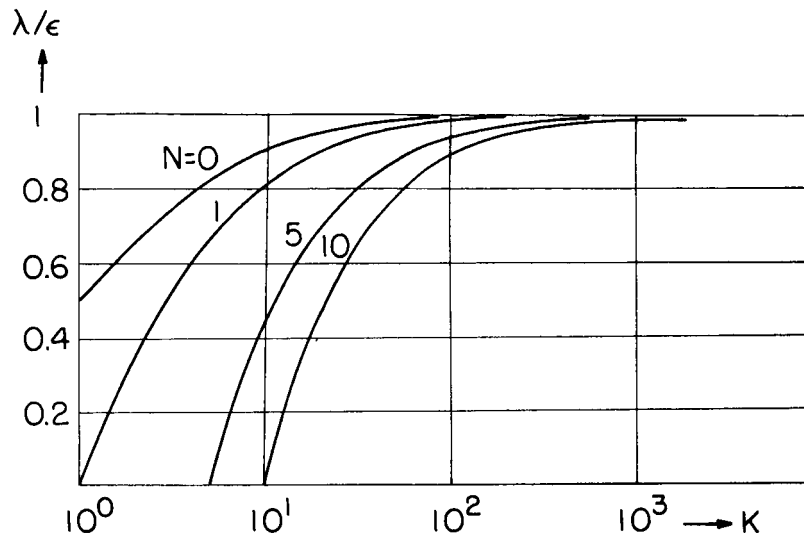
Figure 3.- Influence of the form factor K on the log constant λ.
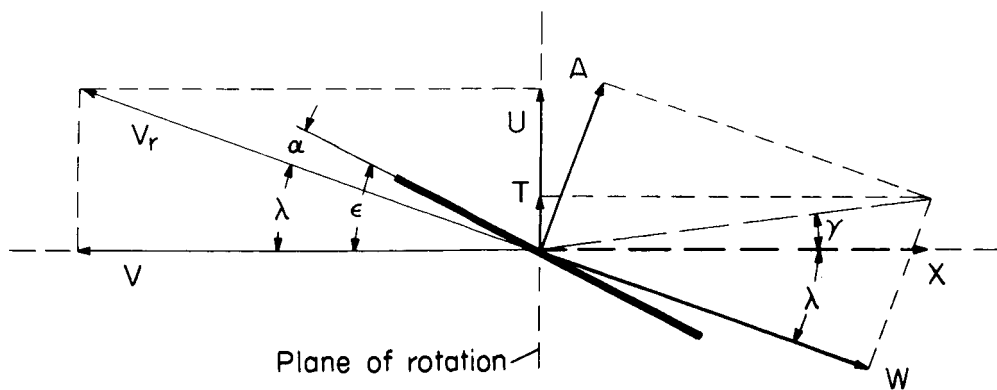
Figure 4.- Velocity and aerodynamic force components on the
"effective" blade section for a log propeller producing a
torque.
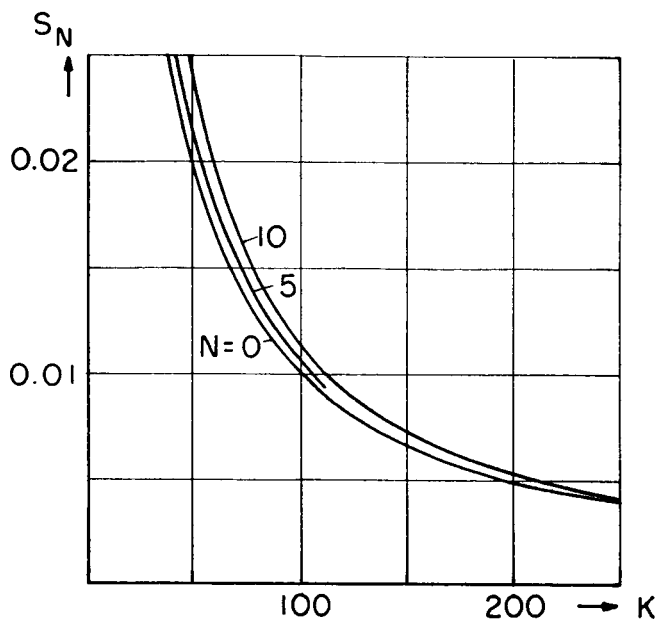
Figure 5.- The relative sensitivity to changes in the friction
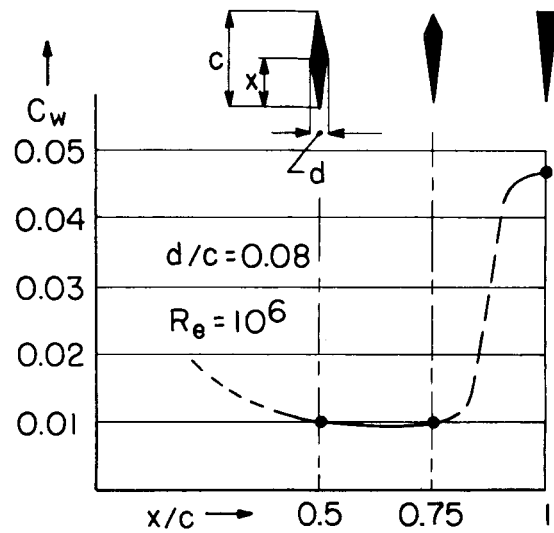coefficient N.
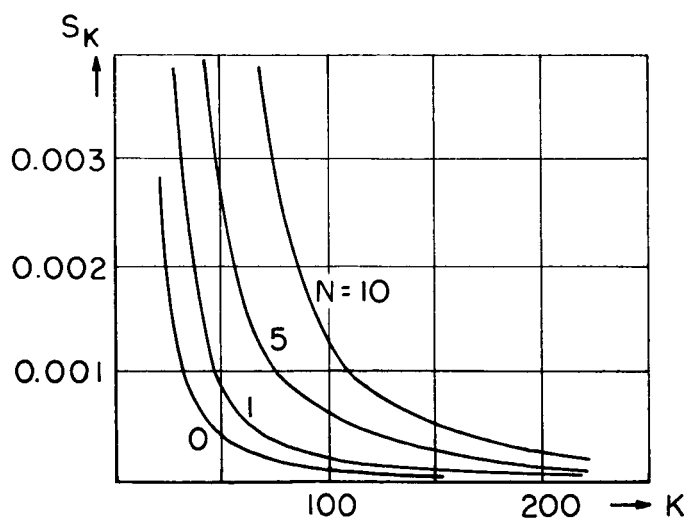
Figure 6.- The relative sensitivity to changes in the form factor K.

Figure 7.- Drag of trapezoidal and wedge profiles.
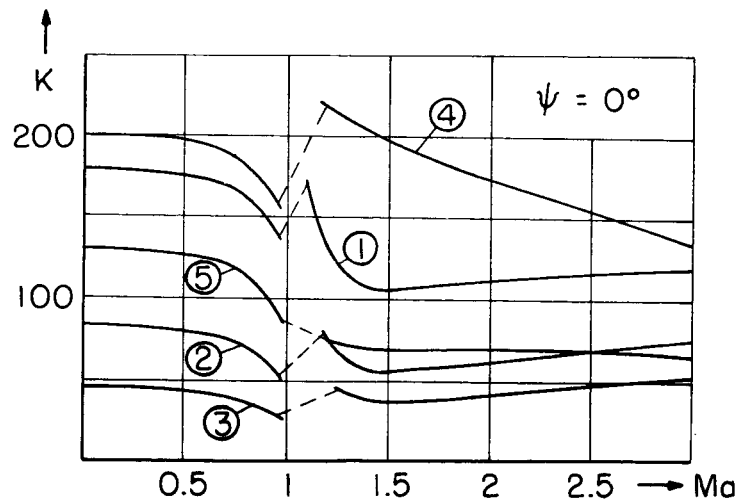
Figure 8.- The form factor K as a function of the Mach number for
the investigated profiles for sweep angle $\psi = 0°$.
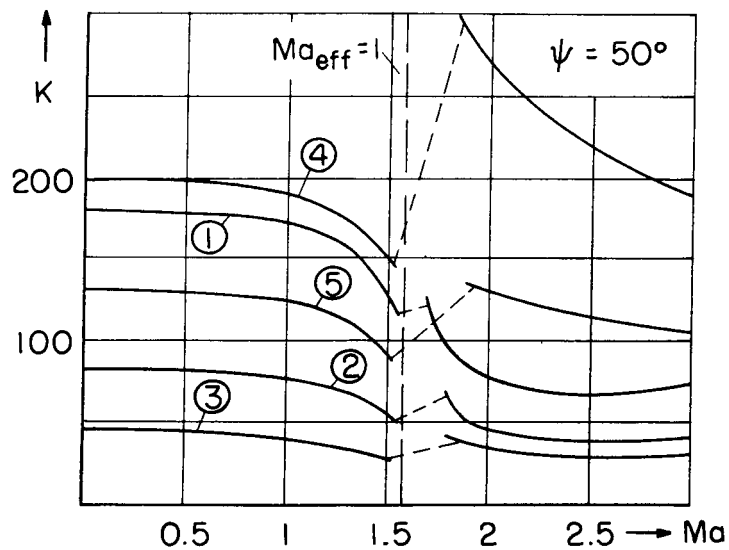
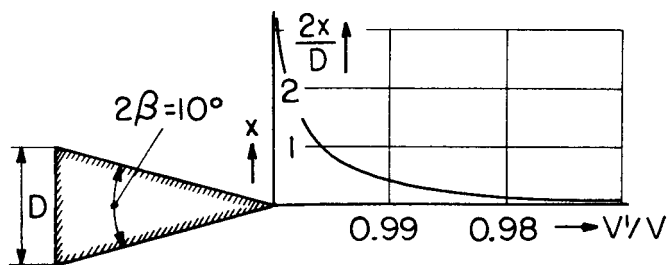Figure 9. - The form factor K as a function of the Mach number for a sweep angle $\psi = 50^\circ$.
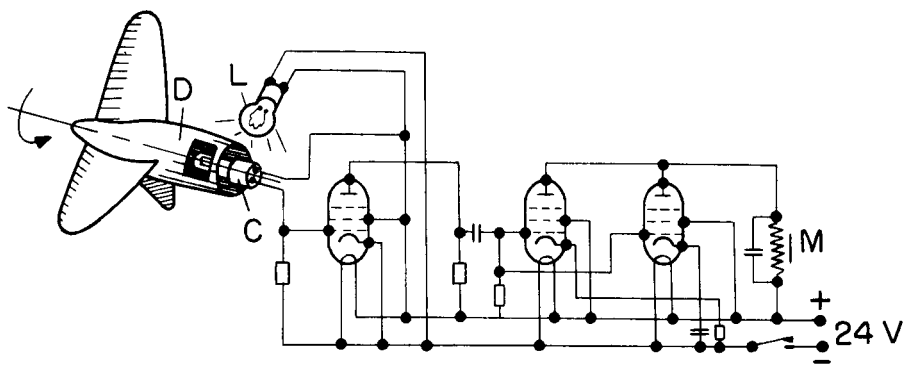

Figure 10.- The local velocities at the vertex of a 10° cone.

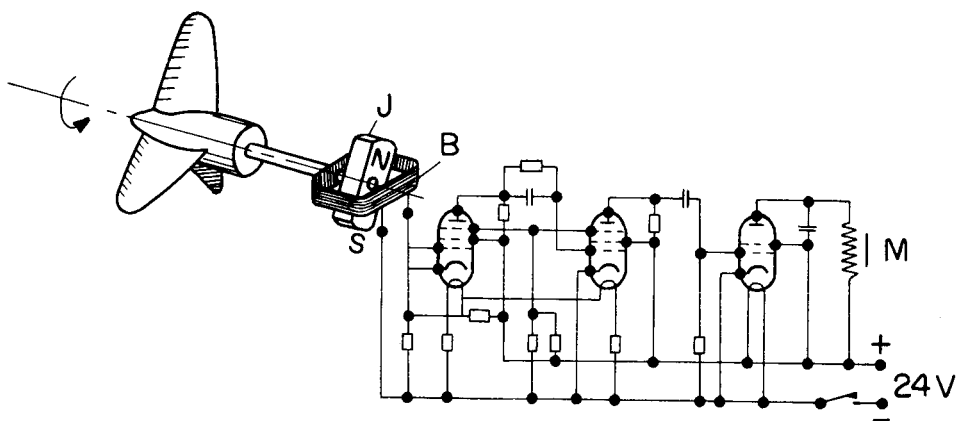Figure 11.- A photoelectrical method of rpm measurement free from reaction.

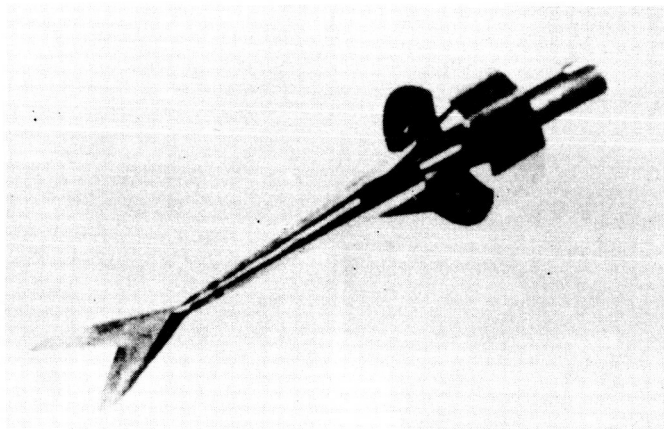Figure 12.- An inductive method free from reaction.

Figure 13.- The new air log of the Instituto Aerotécnico Córdoba
(Argentina) for measurements in the subsonic region, in the
transonic region, and in the supersonic region.